EFFECTS OF AIRCRAFT EMISSIONS ON WEED SPECIES
GROWN IN THE VICINITY OF
HARTSFIELD INTERNATIONAL AIRPORT
MOUNTAIN VIEW, GEORGIA

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SUMMARY

The purpose of this research was to study the possible effect of air pollution upon the growth and germination of several weedy species. The experiment took place in the community of Mountain View, Georgia where it had appeared that plant damage was due to aircraft landing and take-off operations. Weed communities consisting of nine species were planted along a transect at various distances from an aircraft flight path to determine air pollutant effects on community structure. These community plots were sited so that variations in topography and surroundings would be minimized from one experimental site to another. Soil in the community plots was normalized and the weed species were planted in a randomized pattern. In addition, box planters were set out with eight species grown not in community association, but in single species stands. These planters were used in an attempt to circumvent the variation in soil moisture retention observed from one site to another among the community plots. Weed species in both field plots and box planters were maintained during the 1976 summer growing season and were harvested in the fall. Germination plantings of selected weed species were also carried out in which planted seed samples were observed for seedling emergence over a 19-day period. These seeds were planted in flower pots and were set out at existing field plot and box planter sites.

No damage was observed on any plants maintained during the

course of experimentation. There was no correlation between weed growth or seed germination and flight path proximity. Differences in soil moisture retention and microclimate at a given site seemed to affect growth levels to the extent that other observations and conclusions were made impractical.

CHAPTER I

INTRODUCTION

The advent of large metropolitan airports has brought with it a concern over the environmental impact of such air traffic facilities. Both noise and atmospheric pollution present serious problems for areas surrounding large airports, but air pollution research under such field conditions is often a difficult task. The detection of air pollutants can require the substantial effort of advanced chemical analysis of samples obtained through the proper siting and maintenance of air monitoring networks. Furthermore, it is difficult to assess the effects of air pollution on humans since the observation of large populations over extended periods of time is often necessary. Plants, however, may serve as useful living indicators of atmospheric pollution, and in my own research weed species were employed as test organisms. These weeds were observed for their responses after being maintained at varying distances from an aircraft flight path.

Weed species should be good organisms with which to assess the effects of air pollutants for several reasons. Weeds have conveniently short life cycles, are readily maintained under field conditions, and may be sacrificed for experimental purposes. Many aspects of weed ecology have been studied and a summary of such work would be useful in order to convey the various aspects of weed research. Weeds have been studied in the context of agricultural pest control, plant succession, evolution and population genetics. Work by Baker (1963, 1972, 1974) and Young and Evans (1976) dealt with the characteristics and evolution of weeds. Studies in plant succession often deal with the ecology of weedy species, prominent in early seral stages (Keever 1950, Thomson 1943 and Raynal and Bazzaz 1973). In addition to large-scale theoretical studies, a variety of work has been done in the more specific and applied areas of weed biology. The characteristics of geographical ecotypes of several weedy species were investigated by Palmblad (1968), Dickerson and Sweet (1971) and Dedio (1978). Also the behavior of weed seeds in soil has been observed. Oosting and Hymphreys (1940), Roberts and Feast (1972), Barnes and Schrader (1974), Stoller and Wax (1974), Dawson and Bruns (1975), and Willemsen (1975) investigated the viability and germination of weed seeds in a variety of soil burial conditions. Harper et al (1965), Wesson and Wareing (1969), Pickett and Baskin (1973) and Baskin and Baskin (1977) studied weed seed germination and seedling establishment. Hodgson and Blackman (1956), Palmblad (1968), Holt (1972), Ross and Harper (1972), Evetts and Burnside (1975), Williams (1976) and Solbrig and Simpson (1977) investigated competition and niche procurement phenomena in weedy plants. Morphology, development and field ecology of weed species discussed in this paper were studied by Horowitz (1973), Orwick and Schreiber (1975), Stoller (1975), Thullen and Keeley (1975), Wills (1975), Vengris and Damon (1976) and Williams and Schreiber (1976). A very sizeable body of literature exists concerning agricultural weed management. Agricultural research on species used in this particular study were performed by Barrentine (1974), Hendrick et al. (1974), Keeley and Thullen (1975), McWhorter and Barrentine (1975), Parochetti et al. (1975) and Costa and Appleby (1976).

Little research has been done concerning aircraft emissions generally and the effect of such emissions on plant life in particular. Daniels and Bach (1976) reported on gaseous dispersion modelling performed at Honolulu airport. Aircraft emissions and patterns of movement were integrated with meteorological conditions to produce simulations of the impact of aircraft operations. Naugle et al. (1978) performed computer modelling of aircraft emissions at 10 U.S. Air Force bases. No actual measurements of ambient conditions were undertaken in either of these studies, however. George et al. (1972) reported on ambient sampling of particulates, carbon monoxide, nitrogen oxides, sulfur dioxide and organic gasses at Los Angeles airport. Sampling was undertaken at airport field and buildings, in aircraft and in the surrounding two miles of Los Angeles. Elwood and Dieck (1975) reported on the technical approach to analysis of gas emissions of aircraft turbine engines. Fordyce and Sheibley (1975) estimated the levels of the rarer trace elements originating from jet aircraft engines. Jones and Tauscher (1978) found birth defects to be significantly correlated to residence under an airport landing pattern at Los Angeles airport. No investigation into the specific process of teratogenesis was made, however. Work has been done on air pollutant plant damage originating from sources other than aircraft operation, including pollutants such as ozone, sulfur dioxide, nitrogen oxide and hydrogen fluoride. Little has been done concerning hydrocarbon plant damage with the exception of the effects of some low molecular weight compounds such as ethylene and acetylene (Abeles and Heggestad 1973, and Zimmerman 1935). The presence of hydrocarbon aircraft fuel residues was of interest in the Mountain View area.

Although no studies of aircraft emission impact on weeds have been undertaken, some other field research with weeds has been conducted in the Atlanta area. Kuo (1973) studied the effect of urban and rural growth treatments on the development of populations of weed species with both urban and rural origins. Lund (1974) made a thorough analysis of weed communities in heavily urbanized areas of Atlanta, Georgia. Neither of these works, however, investigated the specific processes of man-induced pollution maladies or the gradient effect of any pollutant with respect to weeds.

Near Atlanta's Hartsfield International Airport there was a situation which permitted the observation of weeds grown in a supposedly adverse environmental gradient. The community of Mountain View, Georgia is near the eastern end of the northernmost east-west runway of the Atlanta airport. In October 1975 the author was present when officials from the United States Environmental Protection Agency (EPA) conducted preliminary observations near the Atlanta airport in response to Mountain View citizen protest concerning adverse effects from low-flying aircraft. Brittain (1975) reported initial impressions of adverse "vegetation effects . . . unique to the area."[1] Wiersma (1975)

> . . . detected vegetation damage at the end of both major east/west runways which was characterized by spotting and damage to leaves on a variety of species of plants, was widespread underneath the flight paths but was not readily observable on areas outside the flight paths.[2]

Plant damage appeared to be occurring in a limited area as a result of aircraft operations. As a result of these preliminary observations, EPA proposed a study for the spring and summer of 1976. Native and garden-grown vegetation were to be observed for pollutant damage and a network of air samplers was to be set up in the vicinity of aircraft flight paths.

I designed an experiment which would be conducted at the same time as the EPA study. My research dealt with the possible effect of flight path proximity upon the growth and germination of weedy plants. The presence or absence of foliar damage to experimental plants was of fundamental interest. If any such damage was found it was planned to determine any pollutant gradient effect on plant biomass and survivorship. Community effects such as differential species dominance and species diversity were to be observed as a function of flight path proximity also. Germination tests of weed seeds were also planned to see whether onset of germination or percentage of germination were affected by flight path removal.

[1,2]This is an internal EPA document representing initial impressions and is not a published finding.

CHAPTER II

MATERIALS AND METHODS

Field Plots

In order to observe plant growth influenced by overpassing aircraft, a series of field plots was established in the vicinity of Mountain View, Georgia. This series of plots was laid out in a transect perpendicular to the landing flight path of the northernmost east-west runway of Atlanta's Hartsfield International Airport. This transect was approximately 1140 meters from the eastern end of this runway.

Six sites along this transect were located at approximately 0, 90, 180, 270, 360 and 660 meters distant from the landing flight path. The sites were not colinear owing to the fact that this was a residential area and the locations of suitable free spaces for plots could only approximate a linear transect. A seventh control site was located in a residential area of Atlanta well removed from the airport location. At each of the seven sites, three test plots were laid out in close proximity to one another, each plot measuring 1 x 2 meters. Henceforward "plot" will refer to this 1 x 2 meter tract and "site" will refer to the replicate grouping of three such plots in close proximity.

At each site the existing vegetation was removed and the surface of each 1 x 2 m plot was scraped to a depth of approximately 5 cm in order to remove the bulk of any roots or seeds which may have given rise to unwanted plant growth. (A border of 5 to 10 cm bare ground was left around the edges of each 1 x 2 m plot. Existing vegetation, in most cases a residential lawn, remained to surround each plot and border.) In order to normalize the soil character of the plots, the same mixture of soil was placed in the plots at all six airport sites. This mixture was prepared by removing soil from all six sites and mixing it thoroughly in a collective lot. This mixture was then replaced in the eighteen plots at the six airport sites. The depth of this mixed layer was approximately 5 cm. This soil bed was smoothed, sprinkled with water and tamped firm in preparation for a subsequent step in the planting procedure. A matrix of painted stone markers was then laid out over each plot in order to facilitate the equitable planting of weed seeds. Fifty 20 x 20 cm squares were marked out in each 1 x 2 m plot. Within each of these squares, nine evenly spaced holes (ca. 2 cm deep) were made with a metal or wooden probe in a 3 x 3 square matrix.

In each square, a different species was planted in each of the nine holes. Table 1 presents the nine weed species with their scientific and common names, taxonomic family, locale of seed collection, geographic origin, annual/perennial classification and number of propagules planted per hole. The weed species employed were chosen as species common to this region of the country or as closely related to such species. Although a random number table was not used for this purpose, a random placement of the nine species within each square was pursued by personal selection. The number of seeds planted per hole was dictated by availability of seeds and seed size. *Cassia obtusifolia* and *Panicum texanum* were obtained from the Agricultural Experiment Station at

Table 1. Summary of Information for Weed Species as Planted in Field Plots

Scientific Name	Common Name	Taxonomic Family	Locale of Seed Collection	Geographic Origin of Species	Annual/Perennial Classification	Planted per Hole
Ambrosia artemisiifolia	Common ragweed	Compositae	Illinois	North America	Annual	5
Brassica kaber	Wild mustard	Brassicaceae	North Dakota	Europe	Annual	5
Brassica napus	Rape	Brassicaceae	Minnesota	Not available	Annual	5
Cassia obtusifolia	Sickle pod	Leguminosae	Georgia	Tropical America	Annual	3
Cyperus esculentus	Nutgrass	Cyperaceae	Florida	North America Eurasia	Perennial	1
Panicum texanum	Texas panicum	Poaceae	Georgia	North America	Annual	3
Setaria viridis	Green foxtail	Poaceae	Montana	Europe	Annual	5
Sorghum halepense	Johnson grass	Poaceae	Texas	Mediterranean	Perennial	5
Xanthium canadense	Cocklebur	Asteraceae	Mississippi	North America	Annual	1

Tifton, Georgia. All other species were obtained from the Valley Seed Service in Fresno, California. The seed-filled holes were covered with soil. A total of 9,450 holes were seeded in the course of the planting of all 21 plots. Planting was done between May 30 and June 17, 1976.

The plots were maintained until early fall 1976. During the germination of seedlings, plots were kept moist with four liters of water per day sprinkled from a watering can. If a plot appeared to be excessively dry, additional water was added during these first weeks in order to give all plots an even chance at germination. Once seedlings appeared to be uniformly established throughout the plots (June 25), each plot was given the same water allotment for the remainder of the summer. This allotment was generally four liters per day, although additional or curtailed water was provided dependent upon drying or water saturation of the plots caused by local weather condition. Through the course of the summer, existing vegetation surrounding the plots was kept trimmed so that interference with the experimental communities would not occur. Certain plots were roped off to protect them from neighborhood children and pets.

Harvesting of the plots took place from September 25 through October 26. Each plant was clipped at ground level and placed between newspaper sheets for subsequent counting. An individual plant was defined as the clump of plants of one species originating from one planting hole. Each plant was measured for height and weight. Wet weight was determined using a Mettler P163N balance. The counting of a given plot took place within 24 hours of harvest. Dry weight measurements would have been preferable but the large number of plants collected and treated as individuals precluded this.

Box Plots

During the course of the summer it became evident that moisture stress was having a marked effect upon the growth levels in the field plots. In order to create a system in which moisture stress could be more effectively controlled, a series of garden boxes was constructed. With similar weed communities growing in these soil-filled trays it was hoped that variations in moisture retention ability from site to site could be overriden. One box was set out at each of the seven sites. The garden boxes measured 1.2 m x 0.6 m x 10 cm deep and were constructed from plywood and boards. All boxes were filled with soil taken from Site 6, a few feet from the already existing field plots. Michigan peat was mixed with the soil to give it some fibre content. Six volumes of a 15 cm flower pot were added to each garden box.

Each box was divided into eight zones, each measuring 15 x 60 cm and laid out side by side along the long axis of the tray. Each zone had 30 evenly spaced planting points with one species planted per zone. On July 14-15 weed seeds were planted in the following sequence in the eight zones of each box: *S. viridis*, *C. obtusifolia*, *S. halepense*, *X. canadense*, *C. esculentus*, *A. artemisiifolia*, *B. kaber* and *B. napus*. For *X. canadense* one bur per point was planted. For *C. esculentus* one nutlet per point was planted. For the other six species five seeds per planting point were planted. These box plots were maintained until

October 1976. In an attempt to circumvent the variations of microclimate from site to site, the box plots were watered so that a subjectively equal level of dampness was achieved. The boxes were observed, generally twice daily, to this end. As will be mentioned in a subsequent section, difficulty was encountered in maintaining uniform soil moisture in these box plots. On October 28, all of the species in the garden boxes were clipped at ground level and grouped in pooled lots for each species at each site. The wet weight was determined as before. Since the plants were not taken as individuals as in the field plots, dry weights could be conveniently determined. This was done after each species lot was air-dried for a period of eight months.

Germination Planting

From August 6 through August 25 germination tests were made on each of five selected weed species at Sites 1, 2, 3, 5 and 6. At Sites 2, 3, 5 and 6 three replicates were set out at each of the pre-existing locations of the field plots and box plots. For the Site 1 treatment, Five replicates were set out at three discrete locations. Site 1-A,B, with two replicates was at the existing field and box plot location. Site 1-C (one replicate) was approximately 90 meters east of Site 1-A,B. Site 1-D,E (two replicates) was approximately 150 meters west of Site 1-A,B. All of the subsites of Site 1 (for these germination studies) were directly under the landing flight path. For each replicate, each of five weed species was planted in a separate flower pot. For *B. kaber* and *B. napus* 30 seeds were evenly planted in 15 cm circular flower pots. For *A. artemisiifolia*, *C. obtusifolia* and

S. halepense 20 seeds were evenly planted in 10 cm square flower pots. The seeds were sprinkled over with approximately 1 cm of soil. The soil mixture used in these germination tests was the same used for the garden boxes (six volumes of a 15 cm flower pot of Michigan peat mixed with 70 liters of soil from Site 6.) The flower pots were checked three times daily and watered as necessary to maintain uniform soil moisture. This daily inspection for soil moisture and germination counts was maintained from August 6 through August 12, 1976. A single final germination count was made on August 25.

CHAPTER III

RESULTS AND OBSERVATIONS

Evidence that a pollution gradient exists comes from the findings of research directed by a Las Vegas, Nevada based EPA laboratory for which the author was the field agent during 1976. In a report on this research Brown _et al_. (1977)[3] refer to observations from October 1975 of plant damage in the Mountain View area apparently deriving from caustic airborne compounds. Therefore, to further assess air pollution effects, research was conducted during the summer of 1976. This research revealed no vegetation damage among a wide variety of both crop species and native species in the Mountain View area. Furthermore, these crop and native species showed no fuel or petroleum based residues under chemical analysis. However, after testing of ambient air was performed with high volume samplers, aviation fuel was found to be retained in charcoal samples. At three sites colinear with my own sampling transect (but laid out north to south from the flight path) this EPA air sampling showed maximum concentrations of AF-001 jet fuel to be 45.00 ng/m^3 at 0 meters removal from flight path, 1.20 ng/m^3 at 500 m removal from flight path and 0.379 ng/m^3 at 850 m removal from flight path.

Hester and Roberts (1976) doing related research in Mountain View

[3] At the time of writing, this EPA document was still in preparation and had not been publicly released. Information in this report was made available through the courtesy of the document authors and of Mr. Doyle Brittain of the EPA Southeast Region IV.

found high values for non-methane hydrocarbons at a single, unreplicated site directly underneath the aircraft approachway. This location was the same as Site 1-C for my own germination plantings. At this site the federal guideline value of 0.24 ppm/3 Hr. was exceeded 95% of the time during May-June 1976 observations.

Field Plots

The results of field plot experimentation are summarized in Figures 1 and 2 and Tables 2, 3 and 4. Site 4 was disturbed by dogs and is not included in the data. Both *Brassica kaber* and *Setaria viridis* matured early and by harvest time a valid collection of these species was impossible. No data are included for these species. Graphical inspection of average individual species weight plotted as a function of each field site reveals no gradient treatment effect (Figure 1 and Figure 2). The fluctuations of growth level are erratic from site to site. Table 2 shows the mean number of individuals, mean weight per individual and mean total plot weight of each weed species for each site. The values for mean number of individuals and mean weight per individual are expressed with all plots pooled within a given site. For the field plots, survivorship values as such could not be determined since a planting point may have had more than one propagule planted in it. Data for Plots 2-B and 6-C are not available since Plot 2-B was lost to a heavy crabgrass infestation and Plot 6-C was improperly harvested and was discarded as an invalid sample. For each weed species, Table 3 shows the grand mean plot sample size, the grand mean plot

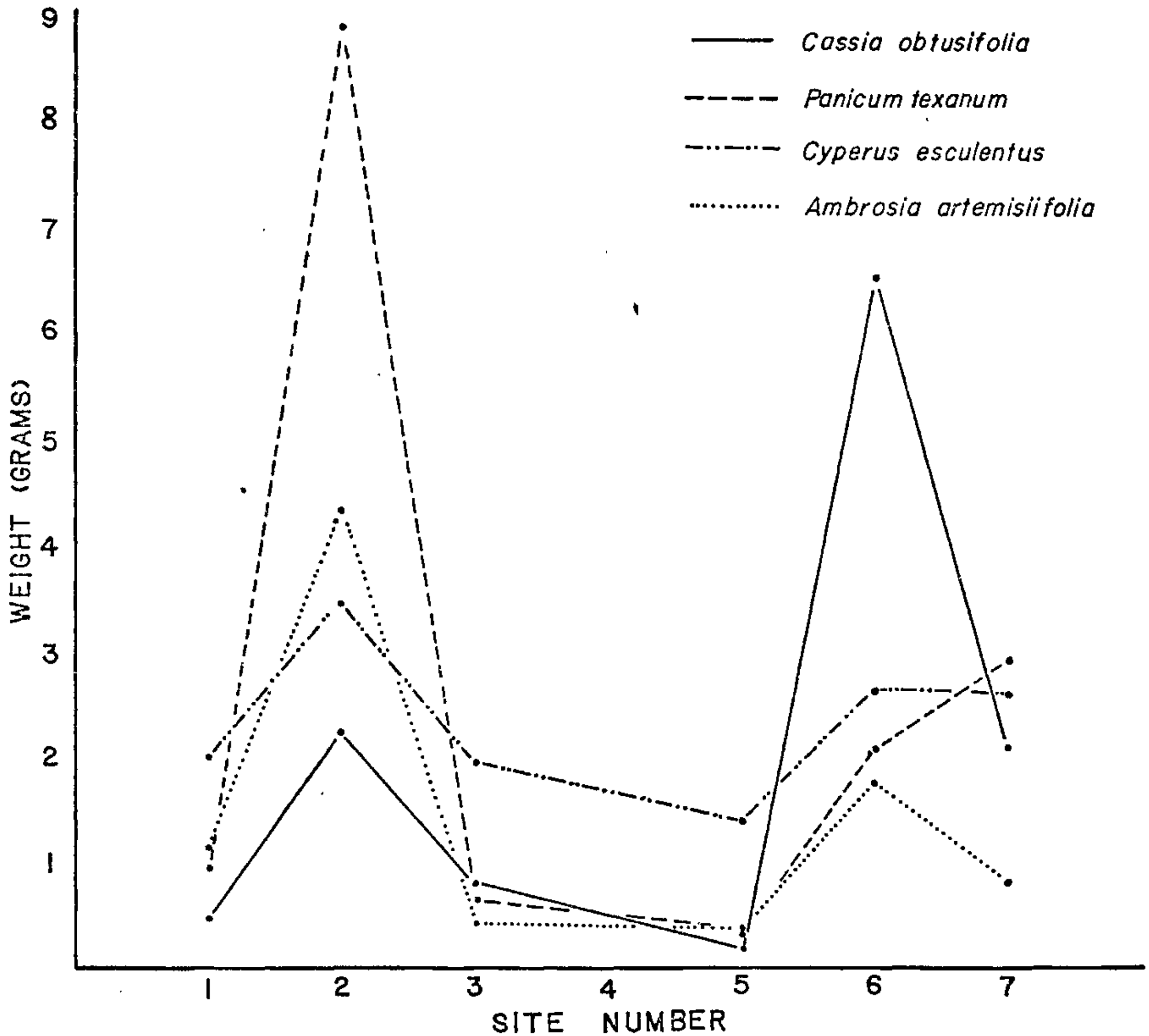

Figure 1. Mean Individual Weights of Species as Related to Site Location

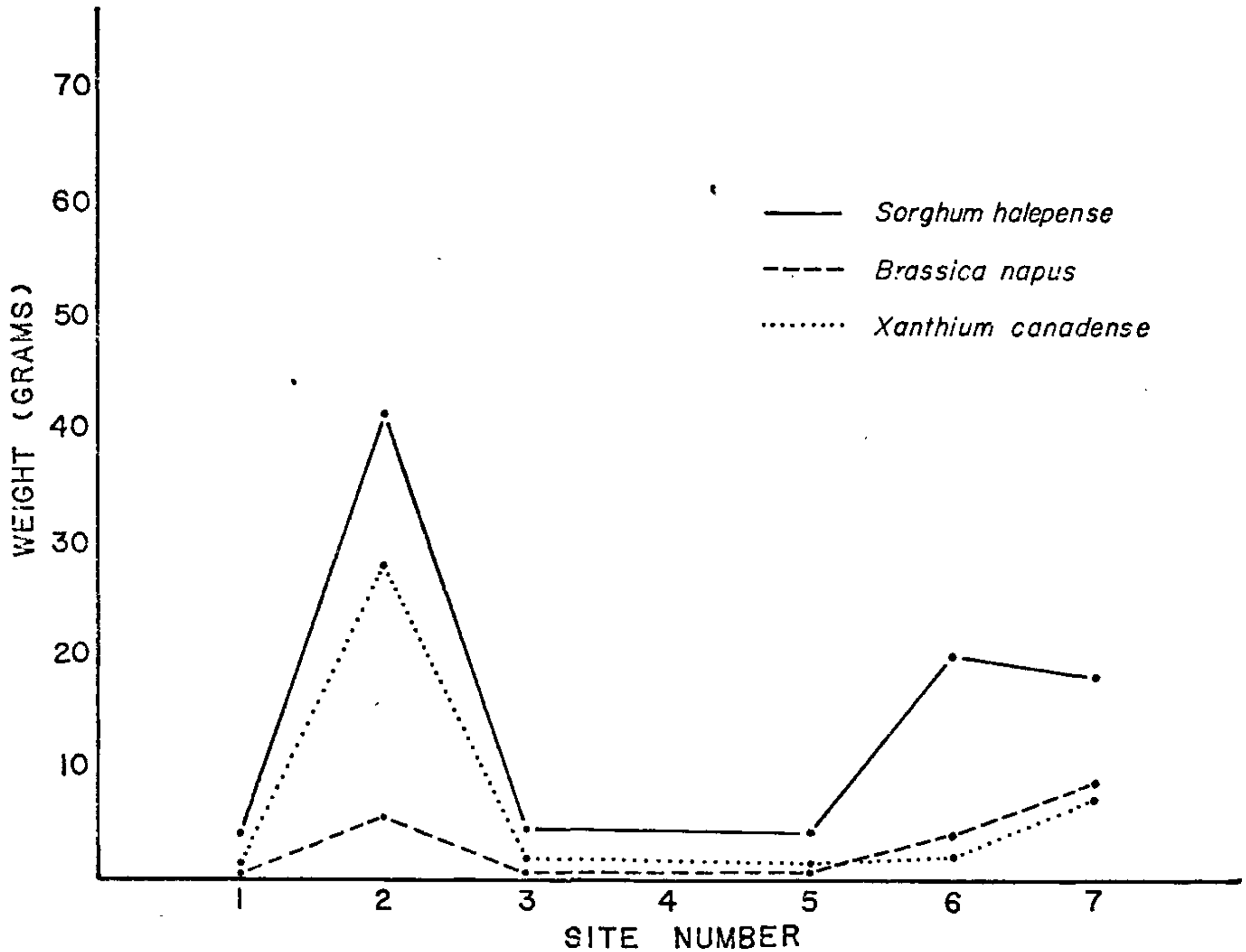

Figure 2. Mean Individual Weights of Species as Related to Site Location

Table 2. Summary of Field Plot Data for Individual Sites
(Site 2 has only two replicate plots. ± denotes standard deviation.)

	Rape	Nutgrass	Cocklebur	Sickle Pod	Ragweed	Panicum	Johnson Grass
Site 1							
Mean Individual Weight (g)	.390 ±.330	1.994 ±1.433	1.240 ±.890	.473 ±.665	1.121 ±.971	.965 ±.787	3.896 ±2.890
Mean Plot Weight (g)	14.485 ±5.920	81.744 ±21.303	18.189 ±5.081	9.772 ±1.997	17.942 ±9.638	31.863 ±15.408	179.206 ±45.619
Mean Plot Sample Size (N)	30 ±14.730	41 ±4.358	14.666 ±3.785	20.666 ±3.785	16 ±2.645	33 ±5.567	46 ±2.000
Site 2							
Mean Individual Weight (g)	5.356 ±11.122	3.468 ±2.503	27.705 ±79.182	2.245 ±1.870	4.342 ±7.433	8.826 ±17.114	41.217 ±40.868
Mean Plot Weight (g)	144.616 ±124.587	143.899 ±39.153	443.289 ±518.845	14.592 ±3.360	84.675 ±84.534	262.431 ±166.210	1935.223 ±785.715
Mean Plot Sample Size (N)	27 ±16.970	41.5 ±0.707	16 ±1.000	6.5 ±0.707	19.5 ±10.606	30.5 ±3.535	46.5 ±0.707
Site 3							
Mean Individual Weight (g)	.615 ±.804	1.945 ±1.689	1.770 ±1.741	.786 ±1.471	.403 ±.419	.685 ±.721	4.558 ±5.116
Mean Plot Weight (g)	20.728 ±22.004	70.677 ±50.223	12.386 ±11.145	7.080 ±7.668	2.821 ±1.581	20.102 ±14.309	204.985 ±123.516
Mean Plot Sample Size (N)	33.666 ±11.590	36.333 ±3.055	7.000 ±2.645	9 ±4.358	7 ±4.358	19.222 ±1.150	32.666 ±3.511

Table 2. Summary of Field Plot Data for Individual Sites (continued)

	Rape	Nutgrass	Cocklebur	Sickle Pod	Ragweed	Panicum	Johnson Grass
Site 5							
Mean Individual Weight (g)	.659 ±.544	1.387 ±1.274	1.243 ±1.434	.215 ±.328	.343 ±.386	.309 ±.297	4.333 ±3.721
Mean Plot Weight (g)	29.680 ±15.589	51.352 ±24.888	19.477 ±12.505	4.452 ±4.572	7.213 ±1.341	7.661 ±2.924	200.772 ±119.278
Mean Plot Sample Size (N)	45 ±1.000	37 ±3.605	15.666 ±5.131	20.666 ±3.214	21 ±1.000	21.333 ±5.033	46.333 ±4.041
Site 6							
Mean Individual Weight (g)	3.756 ±3.677	2.621 ±2.546	1.947 ±2.386	6.506 ±9.446	1.756 ±1.302	2.075 ±1.468	19.940 ±16.103
Mean Plot Weight (g)	148.396 ±33.086	72.098 ±14.266	13.635 ±6.796	45.547 ±40.535	11.417 ±1.480	48.768 ±25.885	816.499 ±97.494
Mean Plot Sample Size (N)	39.5 ±4.949	27.5 ±2.121	7 ±2.828	7 ±2.828	6.5 ±2.121	23.5 ±12.020	41 ±4.242
Site 7							
Mean Individual Weight (g)	8.674 ±11.831	2.594 ±2.098	7.054 ±15.055	2.093 ±3.580	.745 ±.684	2.904 ±3.678	18.266 ±15.973
Mean Plot Weight (g)	419.255 ±125.690	116.353 ±64,705	91.708 ±68.169	21.632 ±2.687	11.437 ±3.431	85.195 ±28.399	785.455 ±57.766
Mean Plot Sample Size (N)	48.333 ±1.527	45 ±4.358	13 ±2.645	10.333 ±3.214	15.333 ±4.041	29.333 ±6.027	43 ±7.000

Table 3. Species Specific Summary of Field Plot Data with All Sites Pooled (± denotes standard deviation.)

	Rape	Nutgrass	Cocklebur	Sickle Pod	Ragweed	Panicum	Johnson Grass
Grand Mean Plot Sample Size (N)	37.750 ±11.497	38.500 ±6.066	12.312 ±4.757	13.062 ±6.806	14.375 ±6.761	27.937 ±6.413	44.500 ±4.000
Grand Mean Plot Weight (g)	127.404 ±167.880	87.023 ±45.825	83.695 ±198.036	15.568 ±17.193	19.401 ±34.139	66.054 ±92.989	600.918 ±629.108
Grand Mean Individual Weight (g)	3.360	2.262	6.797	1.191	1.349	2.382	13.429

Table 4. Site Specific Summary of Field Plot Data with All Species Pooled
(± denotes standard deviation.)

	Number 1	Number 2	Number 3	Number 4	Number 5	Number 6	Number 7
Grand Mean Plot Sample Size (N)	201.333 ±20.033	187.500 ±10.606	166.000 ±14.730	--------	207.000 ±8.544	152.00 ±31.112	204.333 ±0.577
Grand Mean Plot Weight (g)	353.202 ±95.684	3028.727 ±1466.512	323.750 ±243.458	--------	320.609 ±168.700	1156.361 ±122.687	1531.038 ±114.994
Grand Mean Individual Weight (g)	1.740	16.307	2.004	--------	1.543	5.379	7.494

weight and the weight per individual averaged over the combined population of all six sites. For each site Table 4 shows the grand mean plot sample size, the grand mean plot weight and the weight per individual averaged over the population of all seven weed species which were successfully harvested.

Site-to-site significance testing was performed for mean individual weights for each species, mean plot weights for each species and the species pooled mean plot weights. The Student-Newman-Keuls test for comparing means with unequal sample sizes was used for this purpose.[4] The results of this testing are presented in Figure 3 as a group of matrix figures. Those pairs of sites found to be different from each other at the 0.05 significance level are coded with an indicator "*".

The order of total biomass yield of the six sites ranging from greatest to least is as follows: Site 2, Site 7, Site 6, Site 1, Site 3 and Site 5. The order of individual mean weights (with all species pooled) of the six sites is: Site 2, Site 7, Site 6, Site 3, Site 1 and Site 5. These observed orders of growth level have no correlation to the longitudinal progression along the transect of sites; however, daily observation of the sites suggests that the particular growth level of a site was related to the water retention ability and microclimate of that site.

Observations on the general characteristics of the nine weed species as viewed under field conditions are as follows:

Brassica napus. Rape had numerous successful individuals at

[4] The procedure presented by Sokal and Rohlf in *Biometry* (pp. 242-245) was employed.

MEAN INDIVIDUAL RAPE

	1	2	3	5	6	7
1						
2	*					
3		*				
5		*				
6	*		*	*		
7	*	*	*	*	*	

MEAN INDIVIDUAL NUTGRASS

	1	2	3	5	6	7
1						
2	*					
3		*				
5	*	*	*			
6		*		*		
7	*	*	*	*		

MEAN INDIVIDUAL COCKLEBUR

	1	2	3	5	6	7
1						
2	*					
3		*				
5		*				
6		*				
7		*				

MEAN INDIVIDUAL SICKLEPOD

	1	2	3	5	6	7
1						
2						
3						
5						
6	*	*	*	*		
7				*		

MEAN INDIVIDUAL RAGWEED

	1	2	3	5	6	7
1						
2	*					
3		*				
5		*				
6		*				
7		*				

MEAN INDIVIDUAL PANICUM

	1	2	3	5	6	7
1						
2	*					
3		*				
5		*				
6		*				
7		*				

MEAN INDIVIDUAL JOHNSON GRASS

	1	2	3	5	6	7
1						
2	*					
3		*				
5		*				
6	*	*	*	*		
7	*	*	*	*		

MEAN PLOT RAPE

	1	2	3	5	6	7
1						
2	*					
3		*				
5						
6		*	*	*		
7	*	*	*	*	*	

MEAN PLOT NUTGRASS

	1	2	3	5	6	7
1						
2	*					
3		*				
5		*				
6						
7						

MEAN PLOT COCKLEBUR

	1	2	3	5	6	7
1						
2	*					
3		*				
5		*				
6		*				
7		*				

MEAN PLOT SICKLEPOD

	1	2	3	5	6	7
1						
2						
3						
5						
6	*		*	*		
7					*	

MEAN PLOT RAGWEED

	1	2	3	5	6	7
1						
2	*					
3		*				
5		*				
6		*				
7		*				

MEAN PLOT PANICUM

	1	2	3	5	6	7
1						
2	*					
3		*				
5		*				
6		*				
7		*				

MEAN PLOT JOHNSON GRASS

	1	2	3	5	6	7
1						
2	*					
3	*					
5		*				
6	*	*	*	*		
7		*	*	*		

SPECIES POOLED PLOT GRAND MEAN

	1	2	3	5	6	7
1						
2	*					
3		*				
5		*				
6	*	*	*			
7	*	*	*			

Note: Pairs of sites with an indicator "*" were found to be different from each other at the 0.05 significance level.

Figure 3. Matrix Figure Summarizing Site to Site Significance Testing for Mean Individual Weights, Mean Plot Weight and Species Pooled Grand Mean Plot Weights

harvest time, but many of these were stunted, existing at a bare subsistence level. On a moist site (such as Site 2 or 7) this species became verdant and vigorous, much like a turnip head; otherwise this plant was gnarled with leathery leaves.

Cyperus esculentus. Nutgrass had many survivors at harvest also. The leaves were stiff and waxy, somewhat like pine needles. This species appeared to be able to tolerate the dry summer conditions well. The yield of this species from site to site is the most constant of all species.

Xanthium canadense. Cocklebur, planted as a thorny bur, required very moist ground for seedling germination. In dry situations it did not fare well but was very robust at Sites 2 and 7.

Cassia obtusifolia. Sicklepod was not a significant species in the field plots. As will be noted in the observations on germination, this plant had a very low percentage of seedling emergence. The lack of significant presence in this species is curious since the plant is indigenous to the area and was observed growing well in the Mountain View area.

Ambrosia artemisiifolia. Ragweed also had a low percentage germination. Only on moister sites did it show any particular vitality. On sites with little moisture retention the plant was spindly and fragile. This plant is also indigenous and robust stands were seen to occur naturally in the area of experimentation.

Panicum texanum. Moderate numbers of Texas panicum were observed to survive until harvest. It was a plant of low growth habit in most situations. At Sites 2 and 7 individuals were quite robust, producing heavy seed loads. In drier situations the peripheral leaves were often dry and paperlike, with only the central leaves green and healthy.

Sorghum halepense. Johnson grass was a very successful species. It had high germination and survivorship. It could tolerate dryness well and became very aggressive on more favorable sites, growing quite high, producing heavy seed loads and becoming vegetatively reproductive.

Brassica kaber. Wild mustard germinated well but flowered and died early and was not harvestable. It tended to be weak and brittle under field conditions.

Setaria viridis. Green foxtail had very small seeds and did not germinate well. Its presence in the field plots was barely noticeable. By harvest this species had no viable representatives still alive.

Foliar damage, such as might derive from caustic air pollutants, was never observed on any species.

Box Plots

The results from the box plot experiment are presented in Table 5. This table contains the total yield for seven species maintained in these box plots. For each site dry and wet weight yield are listed. The planting box at Site 1 was disturbed by neighborhood children and was unavailable for harvest. The box plot at Site 4 was disturbed by dogs and was likewise unavailable for harvest. The production variation from site to site for the box plots is not so dramatic as it was for the field plots. Site 7 is the most productive and Site 6 is now seen to be the least productive. Site 6 was inhospitable to the point that a number of plants did not survive at harvest. Taken as a whole series, the box

Table 5. Wet and Dry Weights (g) for Species Grown in Box Plots

	Rape	Nutgrass	Cocklebur	Sickle Pod	Ragweed	Panicum	Johnson Grass	Site Total
Site 2								
Wet Weight	0.0	49.5	1.3	2.9	1.7	0.3	20.5	76.2
Dry Weight	0.0	28.2	0.7	0.8	1.3	0.3	9.1	40.4
Site 3								
Wet Weight	7.0	36.2	0.7	2.8	0.6	1.2	17.4	65.9
Dry Weight	1.7	27.0	0.5	0.8	0.4	0.7	8.4	39.5
Site 5								
Wet Weight	5.8	44.5	0.8	1.6	0.1	0.8	19.7	73.3
Dry Weight	1.5	26.9	0.7	0.5	0.1	0.7	10.2	40.6
Site 6								
Wet Weight	0.0	34.4	0.9	1.4	0.2	0.0	7.0	43.9
Dry Weight	0.0	23.5	0.9	0.5	0.1	0.0	4.3	29.3
Site 7								
Wet Weight	146.9	55.1	13.2	8.7	2.1	5.0	32.6	263.6
Dry Weight	17.8	21.6	5.5	2.4	1.3	2.2	12.3	63.1

plots in the Mountain View area conveyed an erratic pattern of growth level. No gradient treatment effect was in evidence and no foliar damage was observed on any of the plants in the box plots. Although the box plots were not directly affected by the drainage characteristics of the ground at a given site, the maintenance of an equitable moisture regime under field conditions proved very difficult. Moisture stress and drying of the plants during field growth did occur and can be seen from the relatively high ratios of dry weight to wet weight observed. Site microclimate seemed to be greatly affected by the character of the natural vegetation surrounding the site. Masses of trees and shrubs could act as windbreaks and areas with a dense naturally verdant flora seemed to be more humid.

The individual plants grown in the box planters were generally much smaller than those grown in field plots. Cyperus esculentus is an exception to this observation, however. The size and vigor of nutgrass in the box plots was much like that found in the field plots. With 30 nutlets planted per box, the individual mean weight of Cyperus esculentus at each site ranged from 1.47 g to 1.837 g. Brassica kaber was observed to survive until harvest when grown in box plots. This is likely due to the fact that planting in the box plots was delayed and thus this species did not have a chance to mature and die before harvest as it did in the field plots. Individuals of Setaria viridis did germinate in the box planters but none survived until harvest. Sorghum halepense plants were not as vigorous in the box plots as in the field planting. However it was still a successful producer of biomass relative to its companion species. It was relatively tolerant to heat and dryness and appeared to have good survivorship of individual plants, although no survivorship data for the box plots were collected. The remaining species of weeds planted in the box plots behaved in a fashion much like that already noted for the field plots.

Germination Planting

The results from the germination testing are presented in Table 6. For each species this table shows the mean number of cumulative germinations observed per day at each site. There is no evidence in these data of either the initial onset of germination or the final proportion of germinations being correlated to flight path proximity. The percent emergence after 19 days for each species was as follows: *Cassia obtusifolia* 3.2%, *Brassica kaber* 46.8%, *Sorghum halepense* 75.3%, *Ambrosia artemisiifolia* 14.4%, *Brassica napus* 85.9%. With the exception of *Ambrosia artemisiifolia*, all germination had taken place within six days.

Table 6. Mean Number of Cumulative Germinations Observed per Day for Seeds of Five Weed Species (± denotes standard error. B. napus and B. kaber germinations are per 30 seeds planted. A. artemisiifolia, C. obtusifolia and S. halepense germinations are per 20 seeds planted. Site 1 has five replicates. Sites 2, 3, 5 and 6 have three replicates.)

	8/9	8/10	8/11	8/12	8/25
Cassia obtusifolia					
Site 1	0	0.60 ± 0.89	1.00 ± 1.22	1.00 ± 1.22	1.00 ± 1.22
2	0	0.33 ± 0.58	0.67 ± 0.58	1.00 ± 1.00	1.00 ± 1.00
3	0	0	0	0	0
5	0	0	1.00 ± 1.00	1.00 ± 1.00	1.00 ± 1.00
6	0	0	0	0	0
Brassica kaber					
Site 1	2.00 ± 2.35	14.00 ± 3.16	15.60 ± 2.88	15.80 ± 3.11	15.80 ± 3.11
2	0	9.33 ± 1.15	11.33 ± 1.53	11.33 ± 1.53	11.33 ± 1.53
3	2.00 ± 1.00	12.67 ± 0.58	13.33 ± 1.15	13.67 ± 1.53	13.67 ± 1.53
5	0	8.67 ± 4.73	12.00 ± 5.29	13.33 ± 4.93	13.33 ± 4.93
6	1.67 ± 1.53	10.33 ± 2.89	14.00 ± 3.61	15.00 ± 3.46	15.00 ± 3.46
Sorghum halepense					
Site 1	0	13.20 ± 3.27	14.80 ± 2.28	15.40 ± 1.82	15.40 ± 1.82
2	0	13.00 ± 3.00	13.67 ± 2.08	15.00 ± 1.00	15.00 ± 1.00
3	0	12.00 ± 1.73	13.67 ± 1.15	14.33 ± 0.58	14.33 ± 0.58
5	0	12.67 ± 2.52	15.67 ± 1.53	16.33 ± 0.58	16.33 ± 0.58
6	0	12.67 ± 0.58	13.67 ± 0.58	14.00 ± 1.00	14.00 ± 1.00

Table 6. Mean Number of Cumulative Germinations Observed per Day for Seeds of Five Weed Species (continued)

	8/9	8/10	8/11	8/12	8/25
Ambrosia artemisiifolia					
Site 1	0	0	0	1.60 ± 0.89	2.80 ± 1.79
2	0	0	0	0	3.00 ± 2.65
3	0	0	0.33 ± 0.58	2.33 ± 2.08	4.33 ± 3.79
5	0	0	0	1.33 ± 0.58	2.67 ± 0.58
6	0	0	0	1.00 ± 1.00	1.67 ± 0.58
Brassica napus					
Site 1	10.00 ± 9.35	24.00 ± 4.47	25.60 ± 2.70	25.60 ± 2.70	25.60 ± 2.70
2	12.67 ± 3.21	26.67 ± 1.15	27.00 ± 1.00	27.33 ± 0.58	27.33 ± 0.58
3	8.33 ± 6.66	24.37 ± 0.58	25.67 ± 1.53	26.33 ± 1.15	26.33 ± 1.15
5	1.33 ± 0.58	22.33 ± 1.53	26.00 ± 1.73	26.67 ± 1.53	26.67 ± 1.53
6	16.00 ± 5.57	22.33 ± 5.69	23.00 ± 6.08	23.00 ± 6.08	23.00 ± 6.08

CHAPTER IV

DISCUSSION

The absence of observable plant damage is an important and curious result of this investigation. This experimentation had as its basic aim the observation of plants adversely affected by environmental pollutants and, more specifically, the determination of possibly differential response of different weed species to such pollutant stress. Further, if any such vegetation damage did indeed occur and if distinct species exhibited varying tolerance in such a situation, it was intended to ascertain the manner in which a measure such as species diversity would reflect proximity to a pollutant source. At the outset, the lack of any pollutant damage makes such concern with differential species response and any concommitant variation in species diversity an irrelevant point.

Although it was not appropriate to consider species diversity variations as correlated to pollutant impact, the design of my experiment was meant to accommodate such a consideration of species diversity. The planting scheme employed would have permitted the computation of diversity indices with no bias derived from uneven community compensation. This approach was followed with the precedent of previous efforts attempting to correlate various environmental gradients with the characteristic composition of species in such gradient situations. Patrick (1949) made a broad attempt to correlate a rather subjective "species diversity" (not the currently understood term) with stream pollution in the Conestoga

Basin, Pennsylvania. Woodwell (1962, 1963) reported on the decrease in complexity of a forest community at the Brookhaven National Laboratory, New York, caused by proximity to an ionizing radiation source. Wilhm (1967) used various diversity indices to show that species diversity in a stream receiving organic waste increased with distance from pollutant outfalls. Kuhlberg (1968) found a more complex algae community structure of fishes in streams as a function of longitudinal distance from stream origin and of stream depth. Species diversity has also been studied with respect to the progress of plant succession by authors such as Monk et al. (1969), Nicholson and Monk (1974), Bazzaz (1975), Tramer (1975) and Squiers and Wistendahl (1977). These authors have drawn upon the ecological applications of information theory. Pielou (1966), Wilhm (1968), Hill (1973), Peet (1974) and Zahl (1977) have all dealt with such ecological application of the species diversity concept.

Despite the absence of overt vegetation damage, there were dramatic differences in the weed growth observed at different field sites. In the Results section of this work it is noted that this was apparently due to factors of soil moisture and microclimate varying from one site to another. Such observations are necessarily subjective since precise measurement of soil water potential and site microclimate was beyond the scope of this work. When field sites were selected I attempted to locate them on reasonably flat areas with no tree cover in the immediate vicinity. The sites would thus be open to both direct sunlight and to the direct deposition of any airborne pollutant. Working in a residential area proved to be difficult since the amount of suitable space for field plots was limited and one had to work with the approval of local land-owners. Sites had to be placed along the chosen transect with a limited amount of deviation perpendicular to this line.

During the course of the summer I was able to get a subjective feel for the sites with respect to moisture retention and microclimate. The sites with lower growth levels had some natural slope which gave rise to very well drained conditions. Of the sites with higher growth levels, Site 2 was in a slight depression adjacent to a house and retained moisture quite well; Site 6 was in a broad flat lawn with no slope whatsoever. Some idea of the effect which slope could have upon the growth level of a plot can be gained by considering the yield of the three individual plots at Site 3. All three plots were colinear in the direction of slope and were placed within a half-meter of one another. Site 3-A was at the top of the slope with Site 3-B intermediate and Site 3-C lowermost. The respective total yield values for these plots are 64.455 gm, 359.342 gm and 547.453 gm. Moisture was retained better in the lower plots and the growth levels were appropriately higher. This agrees with work by Slayter (1957) and Beardsell et al. (1973) in which soil moisture stress caused decreased growth in a number of plant species.

Another factor which may have differentially affected site growth levels was the nature of plant life immediately adjacent to a site. When the natural vegetation around a site was vigorous it seemed to keep the area more humid. Sites which had dense lawns, such as 2, 6 and 7, perhaps fared better because of the ability of such healthy turf to moderate the impact of long hours of intense heat and sunlight. Though the field plot at Site 6 was rather productive, the box plot at this site was the least productive. This discontinuity may be due to the fact that box plots were less affected by soil moisture retention and were more reflective of site microclimate. Site 6 was set in a very large tract of lawn and was subject to full sun all day long; the drying effect of wind at this site was likely considerable since no nearby trees buffered the area. A box planter in this situation without being embedded in the ground would lose moisture quickly. Sites with banks of trees and shrubs at not too great a distance were more protected from drying winds.

With field conditions as hostile as they turned out to be, the relative success or failure of any given species is a subject of some interest. Four species (*Ambrosia artemisiifolia*, *Brassica kaber*, *Cassia obtusifolia* and *Setaria viridis*) had net biomass yield far below that of the other species. Of these, the seeds of three were collected in northern latitudes (*Ambrosia artemisiifolia* -- Illinois, *Brassica kaber* -- North Dakota and *Setaria viridis* -- Montana) and their low yield may be due to the incompatibility of northern species ecotypes with southern climate. Dickerson and Sweet (1971) found just such a phenomenon of ecotypic variation in *Ambrosia artemisiifolia* where northern ecotypes matured and flowered early and southern ecotypes were more robust. Burt (1974) reported similar results while studying ecotypes of *Sorghum halepense* and Palmblad (1969) found germination to vary in ecotypic populations of several weedy species. The behavior of *Cassia obtusifolia* is not explained by any ecotypic phenomenon, however. The seed for this species came from within Georgia and ecotypic misadaptation should not exist. Research indicates that sickle pod is well adapted to hot and dry environments. Creel *et al.* (1968) found that sickle pod seedlings had maximum growth in the 30^{o} to 36^{o} range, while Hoveland and Buchanan (1973) reported that *Cassia obtusifolia* germination was highly drought-resistant. While *Cassia obtusifolia* may have behaved in an anomalous fashion, *Brassica kaber* reacted as might be expected since Hoveland *et al.* (1976) typified wild mustard as a cold-season species which was highly susceptible to low soil potassium.

In contrast to these ill-adapted species, *Sorghum halepense* (collected in Texas) appeared to be in its element in the hot Georgia summer. This species had the highest net production and individual mean weight and appeared to be dominant in all plots. This agrees with work by McWhorter and Jordan (1976) who found maximum growth of Johnson grass to occur at a temperature of 32^{o} C and a maximal experimental light treatment (19000 Lux). Abdul-Wahab and Rice (1967) reported on the ability of Johnson grass exudates to inhibit other weedy species (among them *Setaria viridis*), a fact that may help to explain *Sorghum halepense* dominance in my own studies.

Though not as vigorous as *Sorghum halepense*, other species collected in southern latitudes (*Cyperus esculentus* -- Florida, *Panicum texanum* -- Georgia and *Xanthium canadense* -- Mississippi) exhibited growth greater than the previously mentioned ill-adapted species. Cavers and Harper (1967) found similar results in Britain where species originating in hostile seashore environments performed well in their native situation as well as on more favorable sites. Species from favorable sites did not perform as well as those adapted to harsher environments.

One species which performed well in my own experimentation did not originate in a southern latitude, however. Indeed, *Brassica napus* (rape) was collected in Minnesota and is closely related to *Brassica kaber* (wild mustard), a species which did very poorly. *Brassica napus* seemed to have a tough, waxy surface which permitted it to tolerate adverse summer conditions through reduced moisture loss. Schafer and Stobbe (1973) studied the reactions of rape and wild mustard to the herbicide benazolin and found mustard to be 32 times more susceptible. It was found that leaf penetration in *Brassica napus* was minimal while *Brassica kaber* had high leaf permeability. It is interesting that a species from Minnesota could almost appear desert-adapted with its gnarled, rubbery stalks and waxy leaves.

Another phenomenon involved *Cyperus esculentus*, which is a perennial plant grown from tubers. In the Results section it is noted that nutgrass had the most constant yield from site to site. This may be borne out by the fact that nutgrass was the only species with a grand mean plot weight standard deviation which was less than the mean itself. This constancy of yield (among sites) and the fact that the box planter mean individual yield of nutgrass is comparable to that of the field plots are likely due to the growth of *Cyperus esculentus* from tubers. These propagules had a large food source for the germinated plants to rely upon. The plants thus had an insulation factor unto themselves which had the effect of damping out the variation in species yield caused by the differences in soil moisture and microclimate from site to site.

As concerns the seed germination experimentation, it was straightforward and indicated no enhanced or retarded germination as a result of flight path proximity. Such an investigation was undertaken because of the possible action of some airborne hydrocarbon compound as a phytohormone. There has been experimentation dealing with this possibility. Eplee (1975) reported on the use of ethylene in the control of witchweed, *Striga lutea*. Gaseous ethylene was applied to infested fields in order to deplete seed loads through enhanced germination of witchweed seeds. Holm (1972) found weed seed germination to be inhibited by acetaldehyde, ethanol and acetone which accumulated as volatile metabolites under burial conditions. Abeles (1967) reported on the inhibition of flower formation caused by ethylene in common cocklebur, *Xanthium pennsylvanicum*. In the germination plantings *Ambrosia artemisiifolia* and *Cassia obtusifolia* exhibited low germination percentages. The seeds of these species evidently require special conditions for high levels of germination to occur. Creel *et al*. (1968) report that scarification or seed coat rupture with a pin prick was needed to permit water uptake by *Cassia obtusifolia* seeds with high percentages of germination resulting. Otherwise normal unscarified seed had only a 15% germination after burial in soil for one year at 23° C. Bazzaz (1970) obtains high germination levels in *Ambrosia artemisiifolia* after wet storage of seeds in chilled conditions (stratification). In my work no special handling of seeds was undertaken since some constancy of conditions was desirable and the peculiar requirements of the several species used were not fully known.

In conclusion, it should be said that there was no evidence of air pollutants' causing overt plant damage to experimental weed species (or any other flora for that matter), affecting weed seed germination or affecting growth levels of experimental weed plots. These findings are in agreement with EPA observations of plant life in the same experimental area. The EPA documents referred to in this work show cause for the initiation of experimentation. They indicate that hydrocarbon emissions, presumably from aircraft operations, exist in the experimental area and that no vegetation damage was observed during in depth studies conducted in the Mountain View area. In my own work there was apparent connection between plant growth levels and site microclimate and soil moisture retention ability. This had the effect of overriding the level of resolution available with my experiment.

CHAPTER V

CONCLUSIONS

There was no overt air pollutant damage to weed species grown in the vicinity of Mountain View, Georgia, during the summer of 1976.

The initial onset of germination and the final proportion of germinations of weed seed was not affected by proximity to aircraft flight paths in Mountain View, Georgia.

There was no correlation between flight path proximity and the growth levels of weeds grown in both field plots and box plots.

CHAPTER VI

RECOMMENDATIONS

The problem of the potential effect of air pollutant gradients on the species diversity of plant populations is a topic still open to investigation. The problem of how to create reasonably realistic plant communities while maintaining uniform plot character is important to any further experimentation. The use of a planting box capable of insulating plant communities from local site variations would be a possible solution. Such a planter would have to be rather large, on the order of $1 \times 2 \times \frac{1}{4}$ meters in size, in order to accommodate a sufficiently large community of plants. Subsequent siting of such a planter would have to assure uniformity of site microclimate. Experimentation in less densely populated areas would likely make such siting more feasible than in a residential area. Work similar to that of Kuo (1972), wherein widely separated urban and rural plots are compared, might be conducted with the aim of observing community diversity. Any work dealing with plant/air pollutant interaction would be enhanced by on-site ambient air monitoring. Such sampling equipment with long-term monitoring for the duration of a growing season is expensive and difficult to obtain, however. Any species selected for experimentation should be endemic to the experiment locale, and if the species is widespread, geographically distant ecotypes should be avoided. This would provide for adequate survivorship for all plant species employed.

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